Analysis of triangularity effects on edge turbulence with the GBS code

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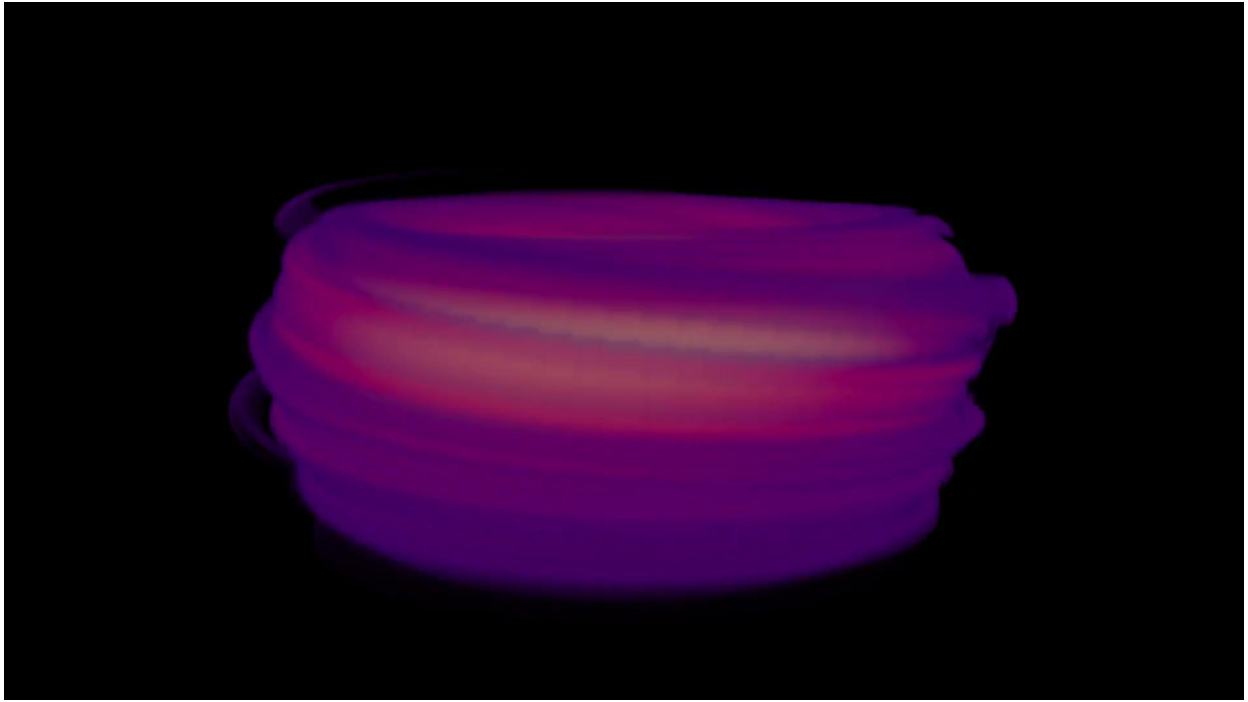
GBS TSVV2 (6th cycle) deliverables

Perform GBS simulations

1. different triangularity (NT and PT)
2. different plasma resistivity and heating power

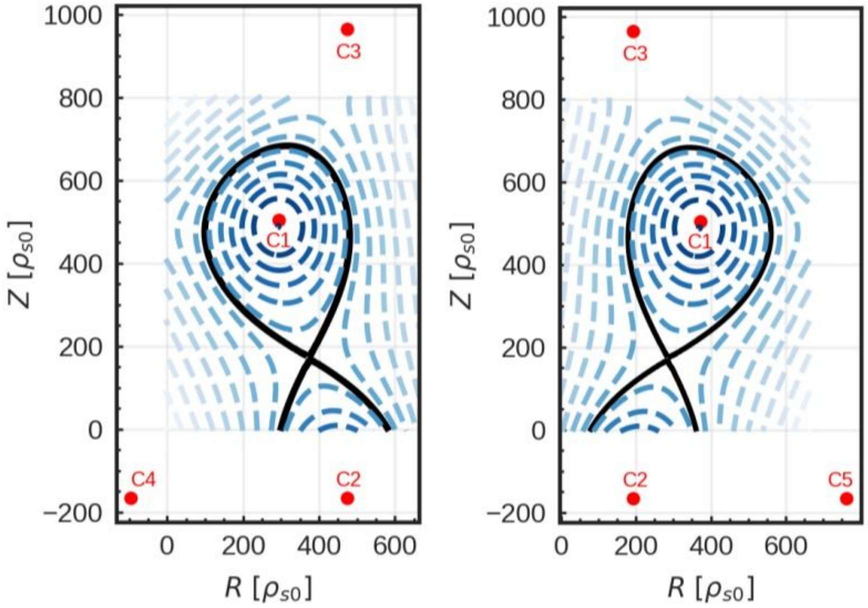
Compared to core plasma, few works have been done for effects of NT on edge plasma turbulence

GBS code: ideal tool for NT/PT simulations



Two-fluid, self-consistent, global, flux-driven turbulence code

Magnetic equilibria generated by external currents

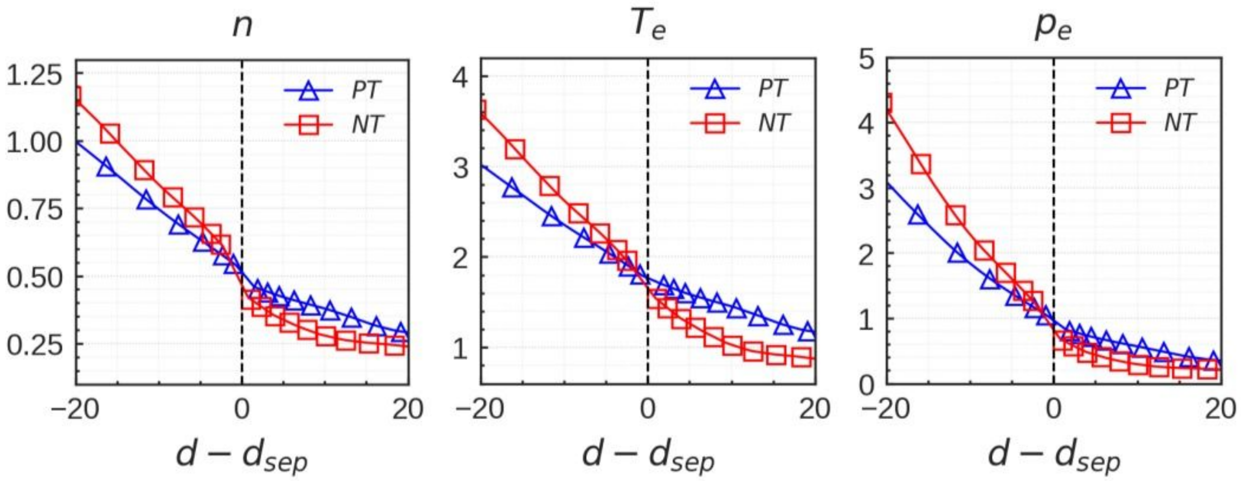


(a) Negative triangularity (b) Positive triangularity

By manipulating external currents, NT/PT (delta=+- 0.3) configurations obtained

Adjust current to have q95 ~ 4 for both cases

Enhanced confinement in NT



(a) Density (b) Electron temperature (c) Electron pressure

Reduced edge plasma turbulence -> enhanced confinement

i.e. steep nTp gradients in NT, strong shear rate, reduced correlation length

Enhanced confinement in NT

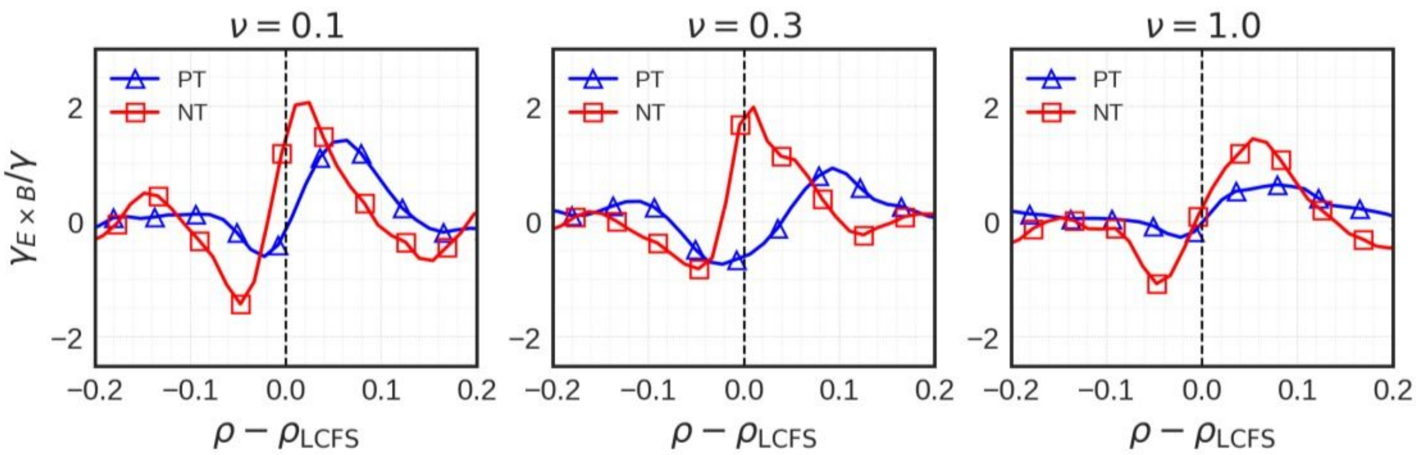


Figure 5: $E \times B$ shear rate normalized by background turbulence growth rate for NT and PT plasma near the separatrix.

Reduced edge plasma turbulence -> enhanced confinement

i.e. steep nTp gradients in NT, strong shear rate, reduced correlation length

Enhanced confinement in NT

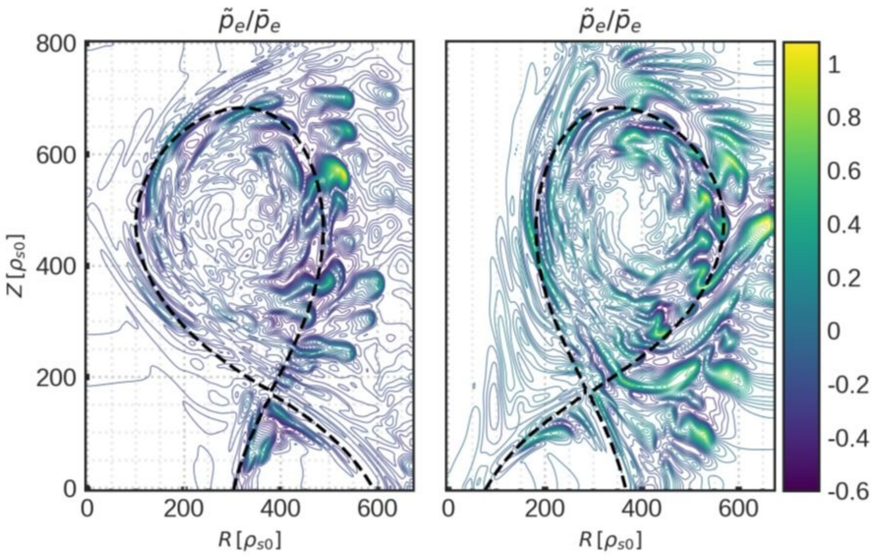


Figure 6: Snapshot of the normalized electron pressure fluctuation for NT/PT plasma with $s_{T0} = 0.025$ and $\nu = 1.0$.

Reduced edge plasma turbulence -> enhanced confinement

i.e. steep nTp gradients in NT, strong shear rate, reduced correlation length

Reduction of magnetic curvature drive of interchange instabilities

Geometrical operators in GBS

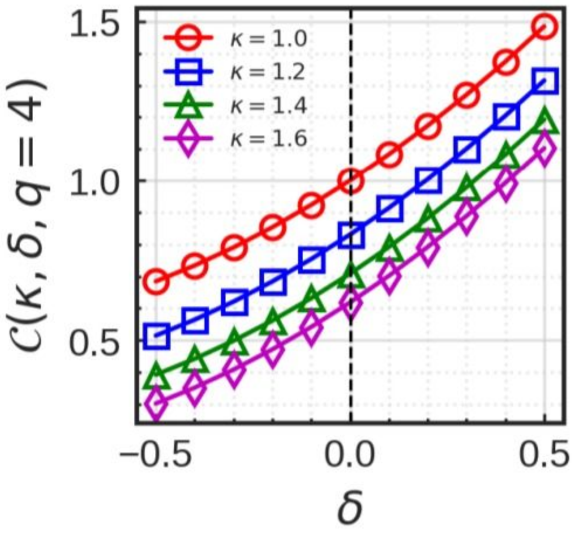
$$[\phi, f] = \mathcal{P}_{xy}[\phi, f]_{xy} + \mathcal{P}_{yz}[\phi, f]_{yz} + \mathcal{P}_{zx}[\phi, f]_{zx}$$

$$\nabla_{\parallel} f = \mathcal{D}^x \frac{\partial f}{\partial x} + \mathcal{D}^y \frac{\partial f}{\partial y} + \mathcal{D}^z \frac{\partial f}{\partial z}$$

$$\mathcal{C}(f) = C^x \frac{\partial f}{\partial x} + C^y \frac{\partial f}{\partial y} + \mathcal{C}^z \frac{\partial f}{\partial z}$$

$$\nabla_{\perp}^2 f = \mathcal{N}^x \frac{\partial f}{\partial x} + \mathcal{N}^y \frac{\partial f}{\partial y} + \mathcal{N}^z \frac{\partial f}{\partial z} + \mathcal{N}^{xx} \frac{\partial^2 f}{\partial x^2} + \mathcal{N}^{xy} \frac{\partial^2 f}{\partial x \partial y} + \mathcal{N}^{yy} \frac{\partial^2 f}{\partial y^2} + \mathcal{N}^{xz} \frac{\partial^2 f}{\partial x \partial z} + \mathcal{N}^{yz} \frac{\partial^2 f}{\partial y \partial z} + \mathcal{N}^{zz} \frac{\partial^f}{\partial z^2}$$

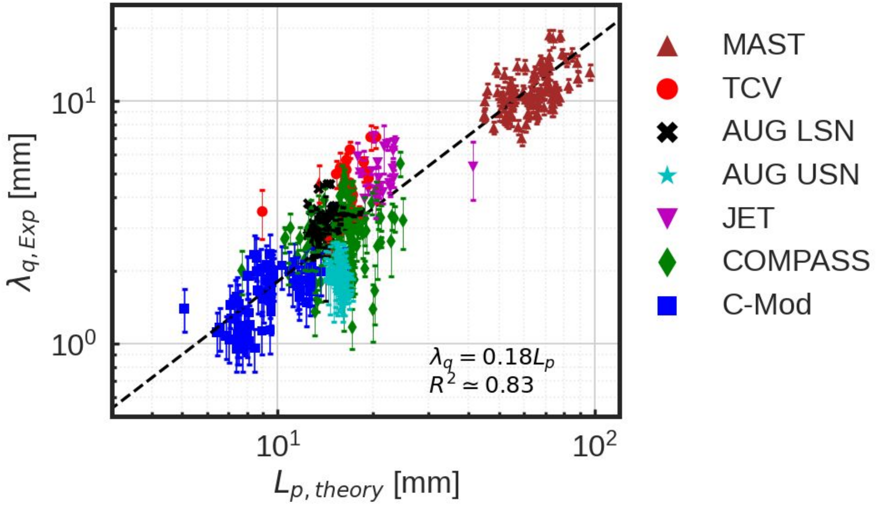
Analytical formula of curvature operator at outer mid plane



Effect of triangularity in determining SOL width

By equating input heating power and outward heat flux (steady state), one can derived analytical expression of SOL width

$$L_{p,theory} \simeq 1.95\, \mathcal{C}(\kappa,\delta,q)^{9/17} A^{1/17} q^{12/17} R_0^{7/17} P_{\mathrm{SOL}}^{-4/17} n_e^{10/17} B_T^{-12/17} L_\chi^{12/17}$$



Extrapolation to larger machines

Parameter	ITER	DTT	SPARC	JT-60SA
R_0 [m]	6.2	2.1	1.85	2.96
a [m]	2	0.6	0.57	1.18
q	2	3	3	3
κ	1.85	1.7	1.97	1.95
δ	0.49	0.3	0.54	0.53
$\bar{n}_e$ [m^{-3}]	4×10^{19}	1.8×10^{20}	3.1×10^{20}	6.3×10^{19}
B_T [T]	5.3	6	12.2	2.3
P_{SOL} [MW]	18	15	29	10
$\lambda_{q,PT}$ [mm]	∼3.7	∼2.7	∼2.3	∼ 7.1
$\lambda_{q,NT}$ [mm]	∼2.2	∼1.8	∼1	∼ 3.3

Table 1: Power fall-off length extrapolation of future tokamaks for NT/PT L-mode plasma. The values of $\lambda_{q,\mathrm{NT}}$ are computed using $-\delta$ in the scaling law.

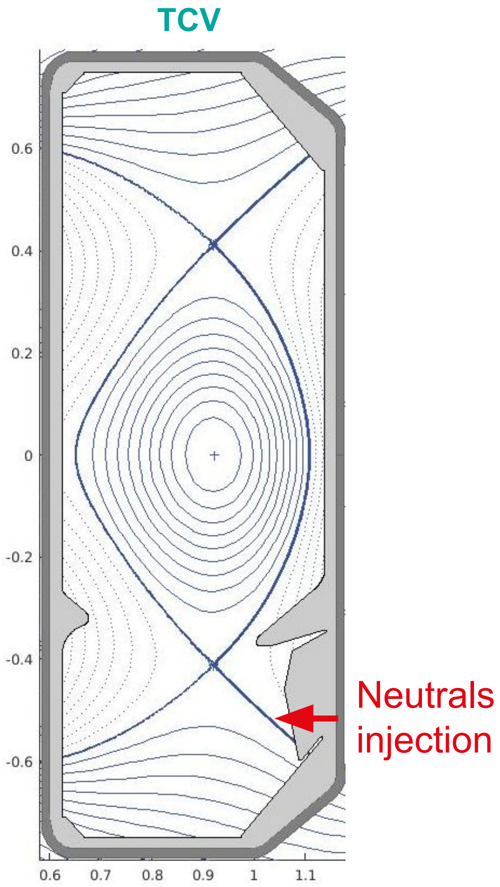
What is next for TSVV2 7th cycle?

During 6th cycle, NT/PT plasma in SN simulations

During 7th cycle, we plan to

- perform double-null (DN) simulations
- impose triangularity
- add neutrals

focusing on heat mitigation in DN + NT + neutrals with detached conditions

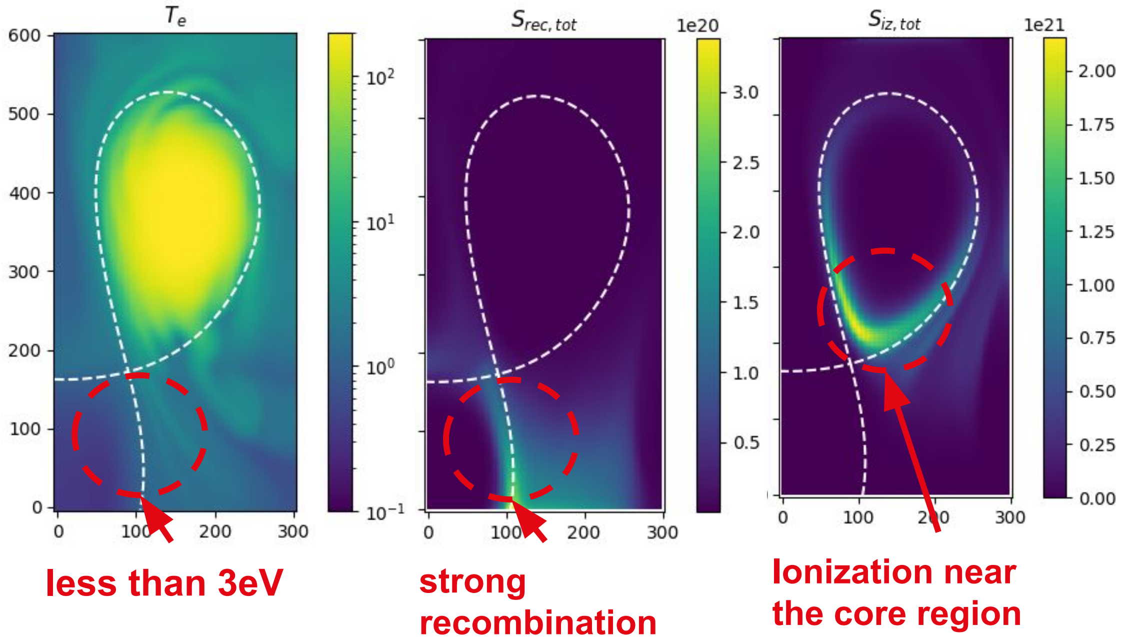


Approach to detachment conditions with neutrals

Simulations of detachment are carried out with GBS in single-null

Detachment achieved with neutral injections

I will explore **the transition to detached conditions compatible with high confinement regimes**



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